General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

DOE/JPL-954527-78/8
Distribution Category UC-63

TENTH QUARTERLY PROGRESS REPORT

Period Covered: August 12 - November 12, 1978

INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

JPL Contract 954527
Project 6072.1

(NASA-CR-158369) INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULENTS Quarterly Progress Report, 12 Aug. - 12 Nov. 1978 (Springborn Labs., Inc., Enfield, Conn.) G3/44
N79-20479
Unclas
16647

For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

ENCAPSULATION TASK OF THE LOW-COST SILICON SOLAR ARRAY PROJECT

The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

APR 1979
RECEIVED
NASA STI FACILITY
ACCESS DEPT.

By

SPRINGBORN LABORATORIES, INC.
Formerly DeBell & Richardson, Inc.
Enfield, Connecticut 06082

December 1978

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

CONTENTS

		Page
1.	SUMMARY	1
2.	INTRODUCTION	2
3.	DISCUSSION OF ETHYLENE/VINYL ACETATE ENCAPSULATION MATERIALS	4
	ETHYLENE VINYL ACETATE MATERIALS	4
	EXTRUDER STUDIES	6
	MODULE FABRICATION ATTEMPTS	9
	A. Vacuum Oven	10
	B. Vacuum Fusion-With Backfill	10
	C. Vacuum Pack	10
	D. Vacuum Pack with Backfill	12
	E. Vacuum Pack-Air Oven	12
	F. Autoclave	13
	VACUUM-BAG FABRICATION	14
	ADHESIVES/PRIMERS	18
	OUTER COVERS	20
4.	FUTURE WORK	22

TABLES AND FIGURES

Table 1 - EVA Extrusion Conditions	7
Table 2 - Estimated Module Encapsulation Costs	17
Figure 1 - EVA Extrusion Operation	24
Figure 2 - Vacuum Bag and Module Assembly	25
Figure 3 - Vacuum Bag Fabrication Cycle	26
Figure 4 - One-Celled Module Fabrication	27
Figure 5 - Vacuum Bag Equipment	28
Figure 6 - Minimodule Glass Superstrate Design	29

1. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for Task 3 of the Low-Cost Silicon Solar Array project (LSSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

During this quarter the technical activities were directed toward the assessment of encapsulation processes for use with ethylene/vinyl acetate (EVA) copolymer as the pottant. Potentially successful formulations were prepared (during the previous quarter) by compounding the raw polymer with ultraviolet absorbers and crosslinking agents to give stabilized and curable compositions. The compounded resin was then converted to a more useful form with an extruder to give pottant in sheets that could be more easily used in lamination.

After experimenting with various techniques, the vacuum-bag process was found to be an excellent encapsulation method. Miniature single-celled and multi-celled solar modules of both substrate and superstrate designs were prepared by this technique. The resulting modules were of good appearance, were bubble-free, and successfully passed the JPL thermal cycle test.

2. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of $0.50 per peak watt ($5/ft^2) (1975 dollars), with a projected first year production rate of 500 peak megawatts. This project has a target date of 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

The materials cost for encapsulating a 1986 module is targeted at 25 cents per square foot (or $8/meter^2, including frame), with the encapsulation system providing protection to assure outdoor system performance for at least 20 years. Successful system performance is defined as a decay in electrical power output not exceeding 50 percent of original value over this time.

Photovoltaic modules are presently envisioned as being composed of six recognizable construction elements. These elements are (a) outer covers, (b) structural and transparent superstrate materials, (c) pottants, (d) substrates, (e) back covers, and (f) adhesives. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use for each of these elements.

Properties considered are cost, transparency, weatherability, and applicability of processing.

This report presents the results of technical activities of the past quarter, directed toward the investigation of encapsulation processes for use with ethylene/vinyl acetate (EVA) copolymer as the pottant.

3. DISCUSSION OF ETHYLENE/VINYL ACETATE ENCAPSULATION MATERIALS

ETHYLENE/VINYL ACETATE MATERIALS

Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide maximum light transmission to the cell surface and optimum power output. Pottants must obviously have very high transparency, with the exception of superstrate bonded designs in which cells are in intimate contact with the transparent superstrate and have no pottant over the front surface.

After an extensive investigation of transparent plastics, ethylene/vinyl acetate (EVA) was selected from a class of low-cost polymers as being a likely candidate potting compound for use in the fabrication of solar cell arrays. Its selection was based on cost (approximately $0.50 per pound) and an appropriate combination of high optical transparency and easy processing conditions. This polymer also shows the most promising properties for immediate use with a small amount of modification, but without extensive development efforts. In subsequent studies, Springborn Laboratories proceeded to formulate and compound a useful grade of this material to yield a polymer with the desired properties*. The base resin selected was Elvax 150 (DuPont), a high melt flow compound with 34% vinyl acetate comonomer composition.

Various cure systems were investigated to give low creep, high-transparency, low scorch with long processing times, and rapid cure at elevated temperatures. Aliphatic additives were also employed to avoid the introduction of UV-absorbing species that might promote degradation. Aromatic compounds conventionally used for crosslinking EVA (triallyl cyanurate,

---

* Springborn Laboratories, Inc., Ninth Quarterly Progress Report, "Investigation of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants" October 1978

dicumyl peroxide, Vulcup-R, etc.) are known to be UV absorbers and could possibly promote instability to weathering.

Three formulations were finally developed for experimental encapsulation studies; one clear; one clear with stabilizers and UV absorbers to improve outdoor weathering; and a third compound containing white pigments to serve as a reflective background in substrate design modules to improve the efficiency.

EXTRUDER STUDIES

Any material to be used in the construction of solar modules must first have the required physical, thermal, optical, and electrical properties; but second must be available in a form that is ammenable to fabrication. In order to use polymeric materials as pottants, it is necessary that the physical form of the polymer be appropriate to the encapsulation technique being employed.

Plastics are commercially available in four basic forms: liquid, pellets, powder, and bulk (chunk). Some polymers are restricted to handling in a specific manner, others may be converted to more useful forms suited to the particular application. Ethylene/vinyl acetate is a versatile polymer that is manufactured in pellet form but may be converted to other forms such as liquid (injection molding) or sheets (extrusion). The sheet form has been found to be the most useful to date and is suited to a wide variety of lamination techniques.

Preliminary investigations of the conversion of EVA copolymer into a useful precompounded sheet form were conducted on a small scale in the laboratory using a Brabender "Plasticorder". This device consists basically of an electric motor, a gear reduction unit, and a miniature single-screw extruder attachment. This equipment was used to determine the basic extrusion conditions for three EVA compounds: clear, clear-stabilized, and pigmented (white).

The temperature profile, back pressure, and screw speed were determined initially with the "Plasticorder" adapted to a 3/4 inch diameter extruder with a 6 inch width film die. All three compounds were found to extrude easily at die temperatures of only 75-80^{o}C. The die back pressure remained fairly constant at 1600 psi and the screw speed was maintained at 60 rpm. The extruded sheet was very clear and manageable; however, the thickness was variable and could not be set precisely using the particular die construction in use.

The preliminary conditions established in the laboratory were then used towards a large-scale pilot plant production. A major extrusion effort was conducted using a Hartig 2½ inch extruder with a two-stage screw containing a mix zone for resin blending.

Large amounts (200-300 pounds) of both clear/stabilized and pigmented compounds were prepared by ribbon blending and were run directly into the extruder hopper. The highest temperature used was 95-100°C at the mix zone and 75°C at the die. The back pressure was 2400 psi for the clear formulation (A8326) and about 3000 psi for the white compound (A8320-B).

The following table lists the average extrusion conditions found for both resins: (See also Figure 1)

TABLE 1

EVA Extrusion Conditions

Extruder: Hartig, 2½ inch diameter
Screw: Two stage, L/D 24:1
Screen pack: (mesh) 20+100+80+20 (at the nozzle)
Die: Deckel set 0.025 inches

Temperature Profile (F°)

	Barrel					Nozzle	Die		
Zone	1	2	3	4	5	8	9	10	11
Set Temp. (F°)	190	200	205	175	175	175	175	175	175
Run Temp. (F°)	195	205	205	220	170	175	175	180	175

Back Pressure: 2400 psi (clear, 3000 psi (white)
Take up roll, temp.: No. 1,2 42°F, No. 3,4 53°F (5-10°C)
Final sheet width: 23.5 inches
Sheet thickness: 0.018 inches, ± 0.001 inches
Interleaf paper: Carter 25W-202

The sheet was extruded at a rate of about 8 feet per minute and was taken up on chrome rollers cooled to 5-10°C. The thickness was uniform across the 24 inch wide sheet at 0.018" ±0.01". The sheets were wound on cardboard cores with release paper interleaving. The interleaving is necessary to prevent the wound sheet from "blocking" or sticking to itself so that the plies are difficult to separate.

The sheet quality was excellent and no cure advancing of the resin was found to have occurred. Blending of the ingredients was found to be uniform in the clear formulation, but the white compound showed some signs of pigment streaking, indicating that the ribbon blending prior to extrusion provides insufficient compounding for this formulation.

The rolled sheets of both polymers were stored in a cool, dry location and used for subsequent experiments in module fabrication.

MODULE FABRICATION ATTEMPTS

Several approaches to module fabrication were attempted, the object being to encapsulate the cell by a fast, reproducible process that did not damage the cell or incorporate bubbles, voids, or any other defect that could serve as a locus for failure. All the techniques attempted were variations of a process employing heat to fuse the EVA pottant and vacuum to remove trapped air and bubbles.

Standard fabrication test modules were constructed measuring 3"x3" and containing one solar cell (57 mm diameter); these were used throughout the range of experiments with only minor variation.

Simple laminates were prepared by assembling layers of the raw materials composing the encapsulation package. For substrate-based designs these laminates consisted of 3"x3" squares of the following materials in order, from topside to underside:

Clear EVA, Formula A8322A(a)
2¼ in. Diameter Solar Cell, Active, Face up
Clear EVA, Formula A8322A
White EVA, Formula A8320B
Super-Dorlux, Vacuum Dried

For superstrate designed modules the materials consisted of, from top to bottom:

Soda-Lime Glass, Primed
Clear EVA A8322A
2¼ in. Diameter Cell, Face up, Active
Clear EVA A8322A
White EVA A8320B

(a) A8322A is a formula for compounded EVA containing only curing agents, but no UV stabilizers. This compound was used for initial fabrications in order to provide specimens for degradation studies.

The lamination processes attempted with the preassembled modules went through a number of changes before evolving to a viable encapsulation method. The processes used and the modifications made are described as follows:

A. Vacuum Oven

The first technique tried was that of simply placing the preassembled module into a preheated vacuum oven and permitting the module to come to fusion temperature under evacuation. The vacuum step is necessary, as modules fused in a circulating-air oven fuse with large amounts of trapped air.

A full vacuum of 30 in. Hg was applied to the oven immediately after loading the module and the fusion temperature was reached in about half an hour.

Laminates prepared in this manner failed due to bubbling and blistering of the molten resin. The highest temperature obtainable before the onset of this difficulty was found to be 70°C ± 5°. Single sheets of EVA responded in the same manner indicating that in part the degassing was also a property of resin composition. Increases in temperature to 90 or 100°C made the situation worse. Modules removed below the 70°C temperature were poorly fused with irregular surfaces, some large bubbles of entrapped air and poor appearance. Variations in the time-temperature-pressure profile brought no improvement.

B. Vacuum Fusion-With Backfill

In an attempt to reduce the degassing and inhibit bubble formation, the vacuum oven was operated at full vacuum until primary fusion had taken place at about 70°C and was then backfilled with nitrogen to ambiend pressure. Nitrogen was used as the backfill gas because the oxygen component of air tends to inhibit the cure of peroxide crosslinked systems. It was expected that the increase in pressure at the fusion point would solve the bubble problem by reducing the vapor pressure of the resin, however, no success resulted from this approach. The highest temperature attainable was 80°C, at which point the onset of irreversible bubbling occurred again. Additional problems included the absence of cure (due to low temperature), cell shifting, and excessive loss of resin over the edges of the substrate.

C. Vacuum Pack

In order to take further steps towards the suppression of bubbles, a direct contact approach was tried. Positive pressure was applied directly

to the surface of the module by assembling a sandwich "pack" of sheet materials around the module. Varying pressures could then be applied to the assembly by placing weights on the top surface. The "pack" consisted of the following assembly:

Top Section:	Weight
	Aluminum support plate, 6"x6"x1/16"
	Cardboard, 6"x6"x1/8"
	Silicone rubber, 6"x6"x1/32"
	FEP film, 3"x3"x0.01"
Middle Section:	Cell lay-up, as in (A)
Bottom Section:	Cardboard, 6"x6"x1/8"
	Aluminum, 6"x6"x1/16"
	Cardboard, 6"x6"x1/8"
	Aluminum plate, 6"x6"x1/16"

Each material was included to provide a specific function.

The FEP film was placed over the module surface to serve as a release surface, the cardboard served to slow down the heat transfer, allowing a longer evacuation time (before fusion); and the aluminum plates serves as rigid support members. The final assembly was taped over the edges to prevent the assembly from shifting.

Loading this pack into the vacuum oven with 0.2 to 0.5 psi (resultant weight on the 3"x3" module surface) pressure resulted in much improved modules with flat surfaces. The limiting temperature was found to be approximately 70°C, as before. Up to this temperature modules could be produced entirely bubble-free, well fused, and of good appearance. Above 70°C degassing began, again resulting in bubble inclusions, although not quite as severely as previously.

The module inside the pack assembly is estimated to reach 70°C in about 45 minutes in the vacuum oven.

The main problem remaining was still that of raising the module to a sufficiently high temperature to cure the EVA encapsulant without the destructive degassing.

The pottant in the modules produced by any of the preceding processes was found to be uncured and completely thermoplastic. Curing does not appear to occur at 70°C - 100°C regardless of how long the resin remains at temperature.

D. Vacuum Pack with Backfill

A combination of the preceding methods was tried. The module "pack" assemblies were fused under full vacuum to a temperature of 70°C and the oven backfilled with nitrogen to ambient pressure as before. The temperature was then raised to 150°C for an additional period of two hours and the modules removed. About 20% of the modules resulting from this process were well fused, bubble-free and showed no signs of cell damage. The remainder were failures and although they had some bubbles, failed more from excessive resin exudation (loss of encapsulant) than any other difficulty. Additionally, the pottant had low levels of cure. Although the polymer was found to cure well in compression mold at 150°C, vacuum packs at the same temperature showed almost no crosslinking. This was then thought to be due to slow and ineffective heat transfer.

E. Vacuum Pack-Air Oven

Successfully fused and bubble-free modules prepared by procedure (c) were left in their pack assemblies and cure was attempted in a circulating oven. Loading into an oven directly at the desired 150°C resulted in the usual bubbling problem, so a more gradual approach was taken. Module packs were removed from the vacuum oven at 70°C and placed in an air oven at 80°C. The temperature was then raised 10°C every 1/2 hour until 150°C was reached. Most modules survived well, with only 20% (appx.) failure rate due to bubbling and degassing. Despite adequate time for equilibration at a sufficiently high temperature, the cure of the EVA was still found to be marginal at Gel contents of 10-20%. These modules did not survive temperature cycling at 90°C and flowed to destruction.

These results suggest that the presence of air inhibits the high temperature cure, even in a pack lay-up; and that a rapid heat transfer is necessary to overcome inhibition effects.

F. Autoclave

A few experiments were run with a miniature laboratory scale autoclave that could be pressurized with nitrogen.

Superstrate cell lay-ups with no pack as described in (A) were placed in a preheated autoclave at 120°C and immediately evacuated to 30" Hg. After a length of time under vacuum to remove entrapped air, the autoclave was backfilled with nitrogen to a pressure of 280-300 psi and left for half an hour. The air was to backfill at the onset of fusion and eliminate bubble formation with the high pressure atmosphere. Modules pressurized after 5, 10 and 15 minutes of vacuum still gave poor results with bubbling and degassing of the EVA.

Throughout the six approaches summarized so far, the following problems were encountered:

(1) Bubble formation - occurring in all cases except (E).
(2) Incomplete cure - occurring in all cases.
(3) Lack of adhesion - occurring in most cases.
(4) Severe resin flow and cell shifting.
(5) Pigmented resin overlapping cell surface - partially solved by using lightly cured pigmented resin.

VACUUM-BAG FABRICATION

A successful and reproducible module fabrication technique was finally achieved using a vacuum bag. The "Bag" consisted of an aluminum picture frame supporting a flexible silicone rubber diaphragm. This frame was then placed on a solid aluminum support plate covered with a thin layer of grease and the whole assembly evacuated through a piece of tubing in the side of the frame. (See Figure 2.) Module lamination was achieved by assembling a "lay-up" of materials as before: (superstrate example)

FEP Film	- release film
Pigmented EVA	- reflective rear pottant
Clear EVA	- transparent pottant
Solar Cells (Face Down)	
Clear EVA	- transparent pottant
Soda-Lime Glass	- superstrate

This assembly was then placed between the support plate and the diaphragm held on the picture frame. Applying the vacuum (30 in.Hg) resulted in removal of air trapped between the sheets of encapsulant and also compressed the asembly to 14.7 psi from the action of the diaphragm. While under vacuum, the entire vacuum bag was loaded between the preheated (150^{o}C) plattens of a hydraulic press which served as the heat source. The ram pressure was just sufficient to close the press and insure good heat transfer to the vacuum bag. The time required for adequate fusion and cure was determined by placing a micro thermocouple over the module assembly. Twenty minutes of cure time was allowed after a temperature of 140^{o}C is reached. Samples of encapsulant from modules prepared in this manner show adequate cure and gel contents in excess of 75%. A graph of the time-temperature-pressure cycle is attached, see Figure 3.

It is necessary to mention that the edges of the module lay up were sealed with masking tape first to prevent the EVA polymer from filling the inside of the vacuum bag. Although the edges were securely taped, entrapped air appears to diffuse through with no difficulty under evacuation.

Solar Power Corporation has recently used this technique to prepare glass-superstrate modules of 11" by 15" dimensions and containing 11 electrically active cells. These modules are fully cured, bubble free, of good

appearance and show no cell damage. Additionally the use of recently discovered GE4179 primer results in excellent adhesion. Glass/EVA specimens using this primer have survived three weeks of water immersion with no signs of delamination.

Springborn Laboratories concentrated on the vacuum bag fabrication of one-celled modules to be used in accelerated degradation experiments (see Figure 4) and Solar Power Corporation (under subcontract) constructed most of the large multi-celled modules (see Figure 5). The modules produced by this method were of two types: superstrate with soda-lime glass, and substrate on Super-Dorlux. Both constructions were of good quality, well fused, crosslinked, and almost bubble-free. One special module was prepared with a cover of Korad X201R acrylic film as an integral part of the encapsulation process (see Figure 6).

The fabrication steps followed in the vacuum bag process may be summarized as follows:

(1) Assemble module construction materials, including the FEP release film (10 mil), and seal the edges firmly with masking tape.

(2) Place the preassembled module between the diaphragm picture frame and lower support plate.

(3) Evacuate the entire assembly through the side connection for at least 5 minutes, and, with vacuum still applied.

(4) Place the vacuum bag between the heated plattens of a hydraulic press or any other heat source capable of making intimate contact.

(5) Allow to cure for 20 minutes after a temperature of 140°C has been reached. Vacuum evacuation is continuous throughout process.

(6) Cool to room temperature, release vacuum, remove completed module.

The advantages found with this encapsulation method may also be briefly summarized, and are as follows:

(a) Rapid fabrication, appx. 1-hour cycle

(b) Free of bubbles and voids

(c) Ease of materials handling

(d) Good cure of the resin

(e) Good adhesion (with the primers used to date)

(f) No cell shifting

(g) Minimal loss of encapsulant during fusion

(h) No cell or interconnect damage

(i) Potential for automation

The large 11 in. x 15 in. modules have successfully passed the JPL thermal cycle test, JPL document LSA 5101-65.

A brief cost analysis was conducted for both substrate and superstrate modules prepared by this method. Calculations were realistically based on actual measurement of the thickness of the pottant layer and determination of the amount of resin used. For a properly prepared module, the total encapsulant profile was found to be in the order of 0.045 inch. This figure excludes the thickness of the substrate or superstrate.

After fusion, the module surface is quite flat and it is assumed that the pottant has become evenly distributed throughout the module. Of the measured 0.045 in. profile, 0.015 layers of pottant reside above and below the cell surface with an additional 0.015 in. layer filling the space between the cells. Subtracting the volume of the cells (at a 70% packing factor) from the encapsulant layer, the volume of pottant used was calculated to be 5 cubic inches per square foot of module surface. The cost of the pottant may be found by multiplying this figure by the cost per unit volume of the resin. The cost of the EVA compound was determined by simply adding the costs of the individual components in the formulation times their respective weight fractions. This was calculated to be $0.7408 per lb. ($0.0267 per cu. in.) for the clear compound and $0.6985 per lb. ($0.0252 per cu. in.) for the pigmented compound.

An estimation of the total encapsulation cost can be calculated by adding in the costs of the other construction elements, as follows in Table 2.

TABLE 2

Estimated Module Encapsulation Costs

Material	$/Ft^2 Superstrate	$/Ft^2 Substrate
EVA, clear	0.0889	0.0889
EVA, pigmented	0.0419	0.0419
Primer, SS-4179 (1)	0.0066	0.0066
Soda-lime Glass (90 mil)	0.26	---
Hardboard, Super-dorlux (1/8 in.)	---	0.10
Total Encapsulation	$0.397/ft^2	$0.237/ft^2

(1) Primer applied at a weight of 0.5 gram (0.001 lb.) per ft^2.

ADHESIVES/PRIMERS

Adhesives and primers or some other mechanism must be responsible for the high reliability bonding of the assembly components to each other in order to insure the structural integrity and long life of the module. Few combinations of materials have been evaluated so far because the bond strengths obtained have been satisfactory. An advantage is presented by the use of ethylene/vinyl acetate copolymers because these materials are adhesives to begin with and are widely used in industry for the formulation of hot melt adhesives.

In substrate module constructions, the EVA to Super-Dorlux bond is found to be satisfactory (7.4 lbs/in., 1.3 Kg/cm) after molding and curing without the use of any adhesion prometers. When these two components are forcibly separated, the failure occurs principally within the immediate surface of the hardboard and the EVA pulls away with a thin covering of Dorlux attached to it. Soaking in hot (60^{o}C) toluene for several hours followed by forced separation leaves a layer of strongly adhering EVA on the surface of the hardboard that appears to be chemically bonded.

Adhesion to glass does not occur as readily, however. EVA molded and cured directly over glass has essentially no adhesion (0.3 lbs/in.) and consequently a primer or adhesive is required. Three candidates were selected from the class of silanes, as these materials are especially formulated as coupling agents for glass surfaces. Only one has been successful to date, GE SS-4179, and has been used for all module fabrication involving the bonding of EVA to glass. In use, this primer is swabbed onto the surface of glass that has been precleaned with detergent, acetone and rinsed in distilled water. The coating weight (wet) is approximately 0.5 grams or .001 lbs per square foot. After an air dry period of half an hour at ambient temperature the glass is ready for lamination. Average peel strengths have not been fully investigated yet but are estimated to be in excess of 10 lbs/in. and the polymer pulls away from the glass with great difficulty leaving a film on the surface. Experimental modules prepared in this manner have withstood three weeks of water immersion with no evidence of delamination or reduction in bond strength.

Due to the immediate success in finding a high quality primer, technical efforts were directed towards other phases of this program. It is realized, however, that a more critical evaluation of primers, lamination techniques and bond permanence is required to establish predictable performance.

OUTER COVERS

Soft elastomeric materials must be used for pottants in order to prevent cracking of the silicon cells due to stresses resulting from thermal expansion differences. Soft materials are prone to soiling and dust retention, however, which reduces the light transmission and impairs the module efficiency. Hard coatings are therefore desirable to avoid this problem. Additionally, the function of UV screening anticipated for the outer cover in order to reduce the effects of photolytic degradation and provide the maximum useful lifetime for the pottant and other components.

The properties of an idealized outer cover may be stated as follows:

(1) High optical transparency (if used on the sunlit side).
(2) Compatible refractive index properties to the pottant that favor optical coupling (if used on the sunlit side).
(3) Chemical compatibility with either the pottant or a suitable primer or adhesive to insure a high reliability bond that will not delaminate during the useful lifetime of the module.
(4) Inherent weatherability.
(5) Ultraviolet light screening properties to protect the underlying pottant (if used on the sunlit side).
(6) Anti-reflective properties to increase the total light transmission (if used on the sunlit side).
(7) Resistance to thermal cycling without melting, cracking, or deforming.
(8) Surface hardness sufficient to retard soiling and to withstand cleaning processes in routine maintenance.
(9) Abrasion resistance to prevent loss of material or sufficient haze to impair the transmission characteristics.

The outer cover of current use and interest is Korad X201-R, supplied by Xcel Corporation, Newark, New Jersey. This product is an acrylic film, available only in a 3.0-mil thickness and not yet commercial; however, commercial development is currently under way. This copolymer film has the following properties:

Tensile strength, psi	4400
Yield strength, psi	4200

Elongation, %	130
Light transmission, %	92
Haze, %	1.3
Gloss at 60°	92
Glass transision (T_g)	88°C

In the recent module fabrication experiments, 201-R was incorporated into the encapsulation package prior to vacuum-bag fusion and cure. The film was placed as a cover over the top piece of EVA in the substrate construction, based on Super-Dorlux. After vacuum-bag lamination the film was found to be physically unaffected, formed a smooth transparent coating over the EVA, and was strongly bonded to the surface. A miniature module was immersed in water for a one-week period. No evidence of delamination of the Korad film could be noticed.

No primers or adhesives were used with the film in the lamination process. The bonding is thought to be a result of the cure mechanism of the EVA. Free radicals generated by the decomposition of the peroxide cause the crosslinking of the EVA by abstracting a hydrogen atom from the polymer chain and then permitting the polymer macroradicals to recombine, thereby forming the crosslink. This is also a known effect in polymers of acrylates, which are probably a component of the Korad film.

It is suspected that the film is chemically crosslinked to the EVA surface in the fusion/cure process and requires no further adhesive aid. Critical and quantitative studies of adhesion and permanence will follow. The cost of the 201-R film is expected to be in the order of $0.05 per square foot.

An additional possibility for this film is that of chemical modification of the surface. Saponification of the surface with dilute alkali may be used to regenerate carboxylic acid functionalities which could then be ion exchanged with an ion such as aluminum. There may then result surfaces with improved properties such as increased abrasion resistance, rain and humidity resistance, and more closely matched refractive index characteristics.

4. FUTURE WORK

Plans for the following quarter will include the following technical activities:

(1) Reformulation of EVA to lower the cure temperature and time and if possible, remove the volatile components that may contribute to gassing and bubble formation. The properties to be improved may include:
   (a) Lower temperature cure
   (b) Faster cure time
   (c) Fewer ingredients, if possible
   (d) Lower content of volatile components to reduce the possibility of bubbling
   (e) Optimization of the internally compounded UV stabilization system
   (f) The possible incorporation of compounds such as silanes to improve the adhesion to substrate or superstrate surfaces

(2) Evaluate a new product being released by DuPont called Elvaloy 837 and 838. This compound is a high molecular weight modified ethylene/vinyl acetate in powder form that may permit other methods of encapsulation such as fluid bed coating to become possible.

(3) Construction of 11 inch by 15 inch modules containing 11 cells of 90 mm diameter. These modules will be based on the best EVA formulation and encapsulation technique to date and will be laminated to a UV screening acrylic outer cover. These modules will undergo performance evaluation at JPL.

(4) Adhesive studies will be emphasized in the following quarter and the factors determining the success of bonding EVA to other materials such as glass, wood and metals will be determined.

(5) Experiments with the surface modification of acrylic outer cover materials will be conducted to improve surface hardness, abrasion resistance and resistance to water permeability.

(6) Preliminary work with other potentially useful potting compounds such as ethylene-propylene rubber, acrylic rubber and PVC plastisol will be started.

(7) Artificial accelerated aging experiments with the RS-4 sunlamp and Weather Ometer will be continued to assess the effects of UV degradation on a variety of materials including:

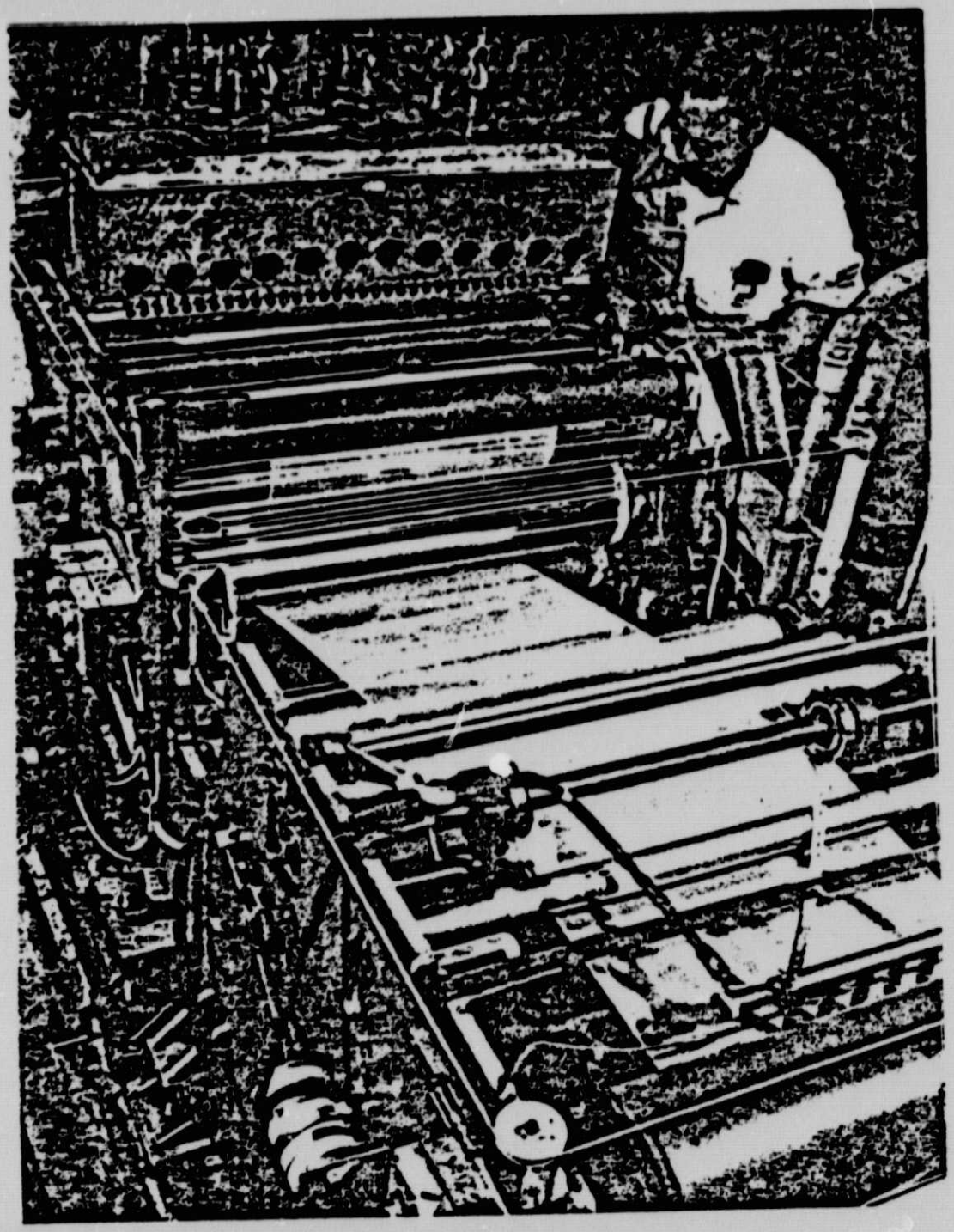
Uncrosslinked (unstabilized) EVA
Crosslinked, Unstabilized EVA
Crosslinked, Stabilized EVA
Crosslinked, Stabilized EVA with Acrylic/UV Stabilized Coating
Crosslinked, Stabilized EVA with Glass Cover
Unstabilized Polyethylene Control
Zinc Oxide Stabilized Polyethylene Control

A new window material, B-270 glass, will be exposed and evaluated for solarization effects and general suitability for use in the carbon arc Weather-Ometer. This glass has been supplied by JPL and exhibits a sharp wavelength cut-off at 290 nanometers. Its purpose is to replace conventional Corex filters that transmit light below 290 nm.

Figure 1

EVA EXTRUSION OPERATION

Hartig 2-1/2" Extruder
Two-Stage Screw - 24-Inch Die



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2

VACUUM BAG AND MODULE ASSEMBLY

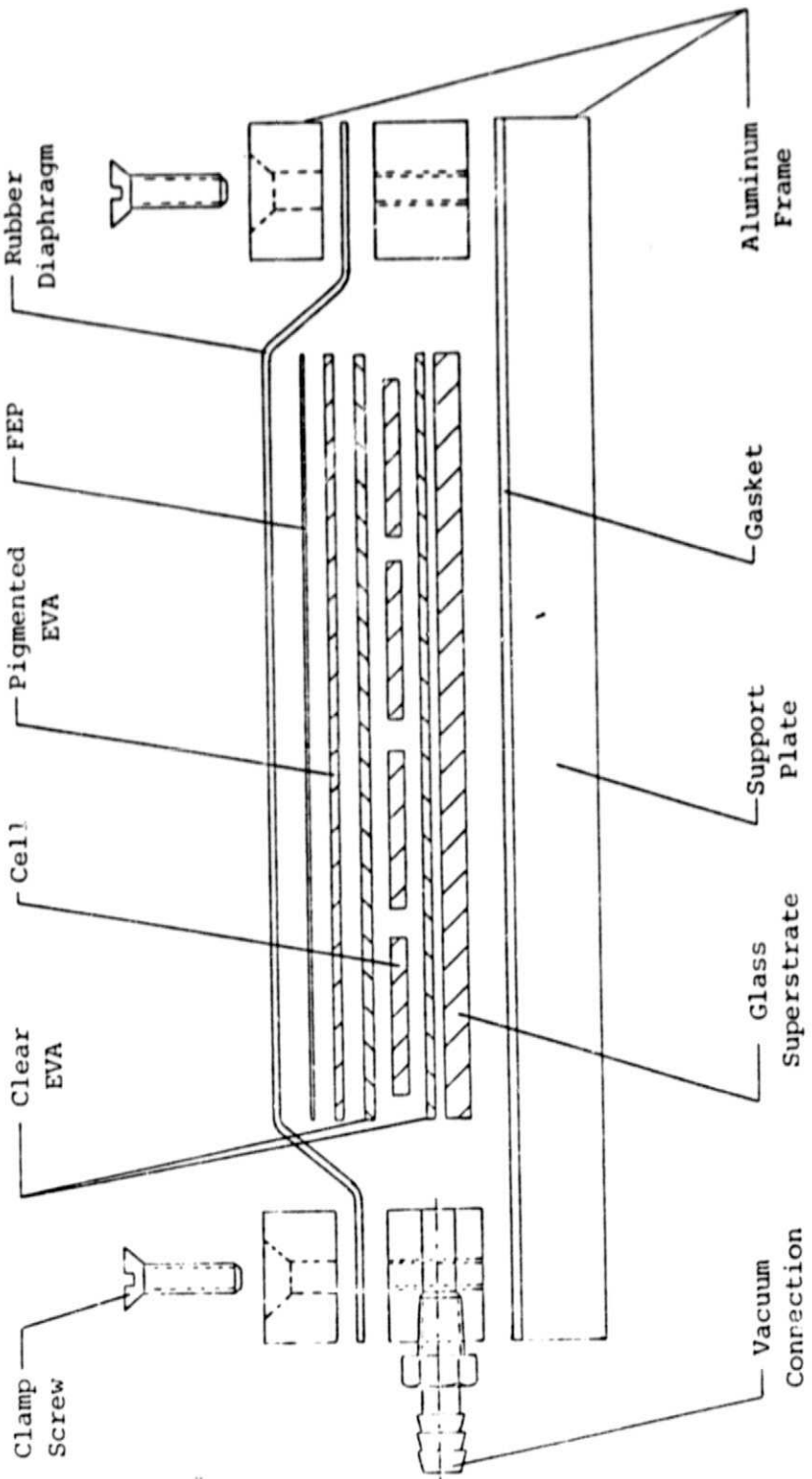
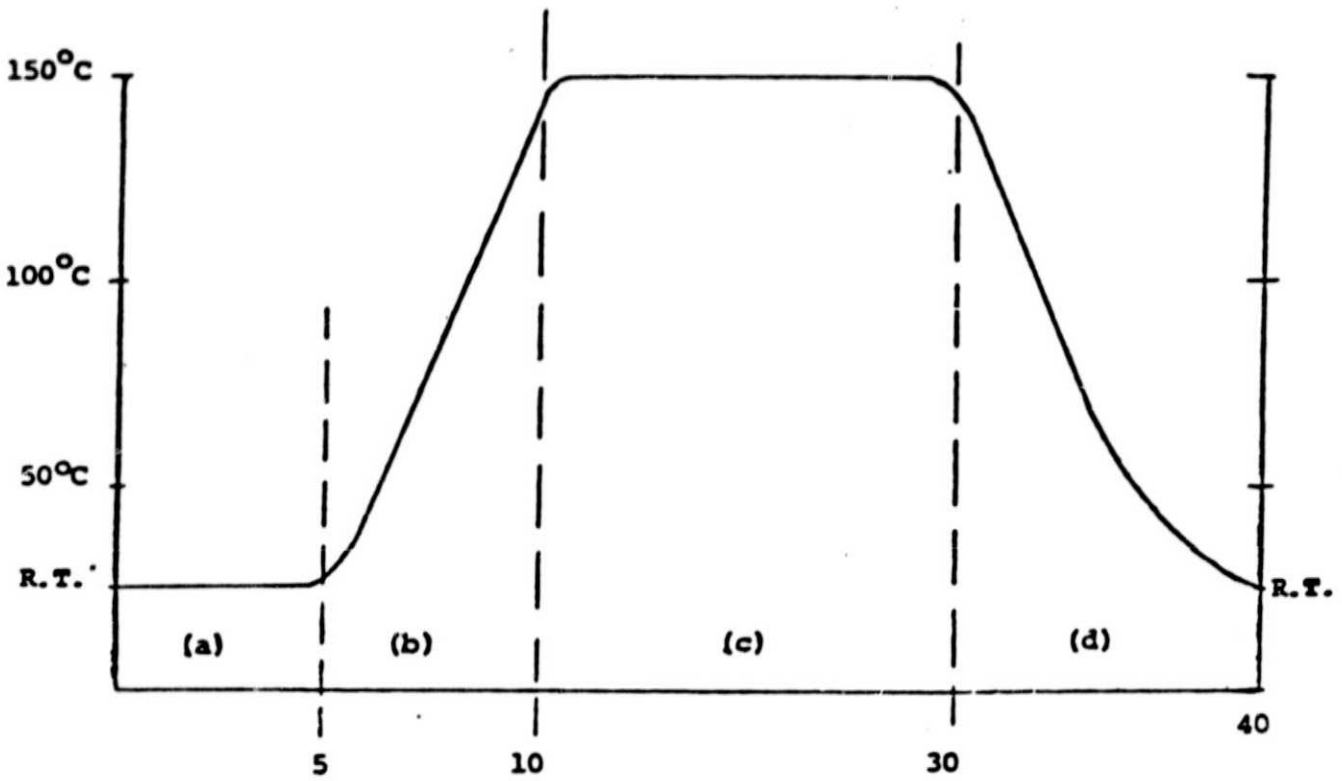


Figure 3

VACUUM BAG FABRICATION CYCLE

11"x15" Modules
A8346

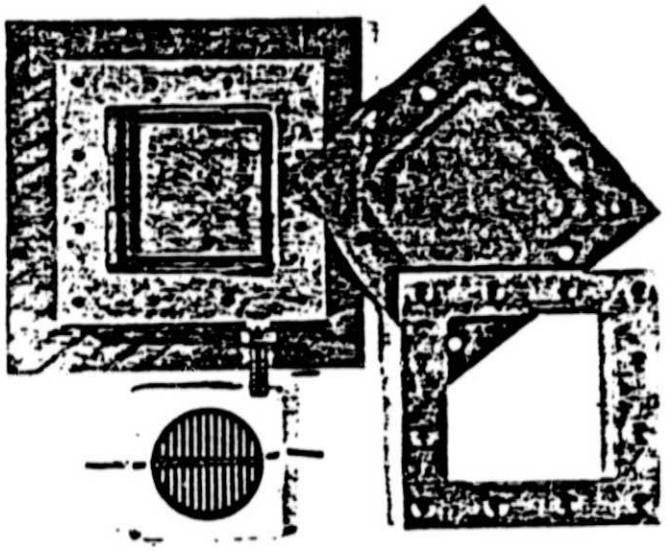


- Vacuum Applied Throughout Cycle, 30 in. Hg.
  - (a) Room Temperature Evacuation
  - (b) Onset of Heat Cycle
  - (c) Fusion and Cure
  - (d) Cooling

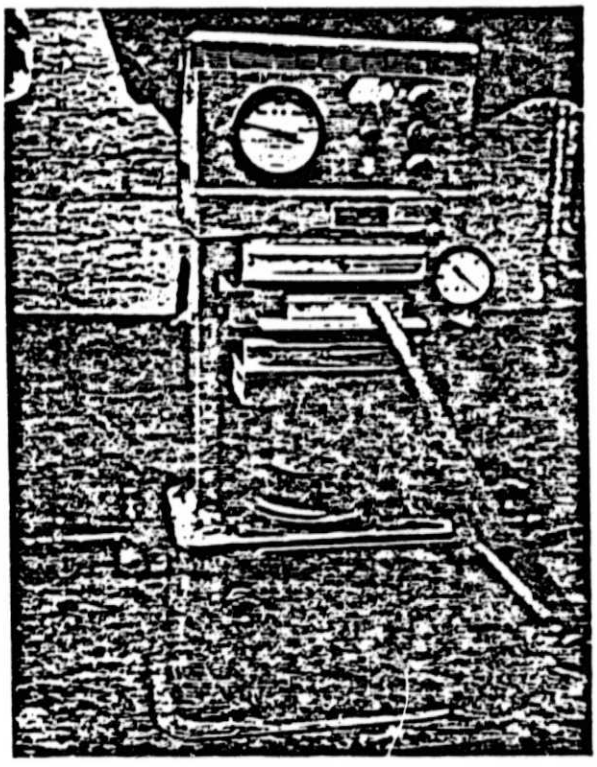
ORIGINAL PAGE IS
OF POOR QUALITY

Figure 4

ONE-CELLED MODULE FABRICATION
(SPRINGBORN LABORATORIES)



VACUUM BAG ASSEMBLY

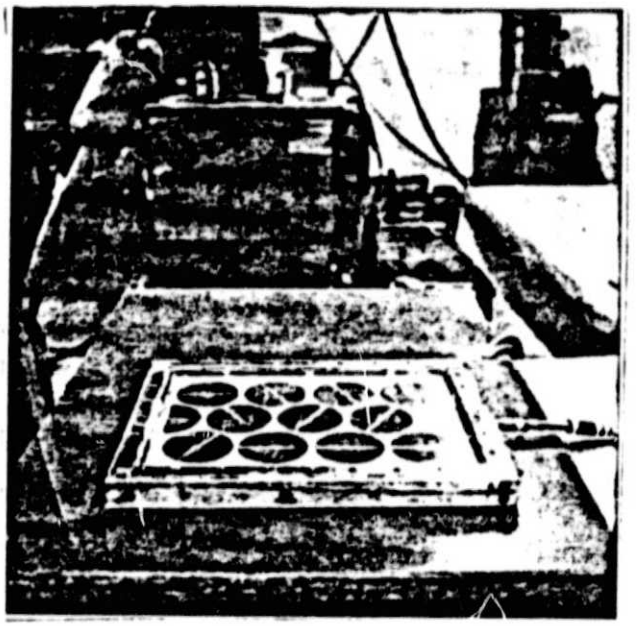


EVACUATION, FUSION,
AND CURE IN
HEATED PLATEN PRESS

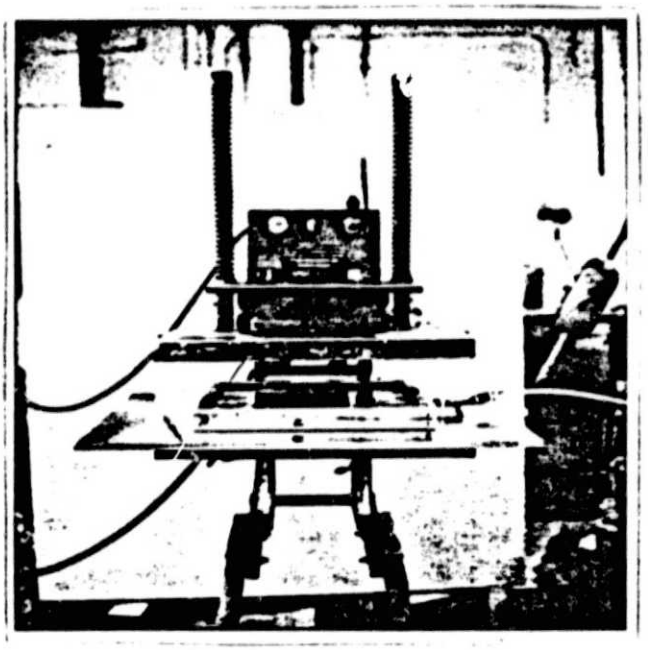
Figure 5

VACUUM BAG EQUIPMENT

SOLAR POWER CORPORATION



VACUUM BAG AND MODULE



VACUUM BAG AND HEATED PRESS

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 6

MINIMODULE

GLASS SUPERSTRATE DESIGN